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Fast Neutron and Gamma-Ray Detectors for the CSIRO Air Cargo Scanner

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The Commonwealth Science and Industrial Research Organisation (CSIRO) has been working with Australian Customs Service to develop a scanner capable of directly scanning airfreight containers in 1-2 minutes.

A critical aspect of the CSIRO Air Cargo Scanner has been the development of fast neutron and gamma ray detector arrays and electronics with the following desirable characteristics:

- High efficiency, particularly for fast neutrons as the brightness of conveniently available neutron sources is low;
- Small detector size. The size of the individual elements of the detector array determines the spatial resolution of the transmission images. A small detector element is desirable to provide sharper images but at the expense of increasing cost and complexity.
- The cost of detector and signal processing electronics should be less than about US$200 per detector channel.

The CSIRO Air Cargo Scanner at Brisbane Airport contains 704 neutron detectors and 352 gamma detectors assembled on array boards. The fast neutron detectors in the scanner use orange-light emitting plastic scintillators (20x20x75 mm) and the gamma-ray detectors use CsI(Tl) scintillators (10x10x50 mm). Each detector uses photodiode readout and was coated to maximise light collection at the photodiode. A significant technical challenge in the current project was to develop low noise/high gain amplifiers at a relatively low cost.

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1. Introduction

CSIRO has developed the fast-neutron/gamma-ray radiography (FNGR) method for the rapid scanning of air freight containers [1,2]. By combining 14 MeV fast-neutron and ^{60}Co gamma-ray radiographic measurements, images are produced that represent both the density and composition of the contents of a container. CSIRO has installed a full-scale commercial prototype scanner at an Australian Customs Service purpose-built facility at Brisbane International Airport. Customs are undertaking a trial of the technology in a real-time working environment as well as a rigorous evaluation of the technology and associated business processes.

The key requirements of detectors for the CSIRO Air Cargo Scanner are:

- high efficiency for both 14 MeV neutrons and ^{60}Co gamma rays (1.17 and 1.33 MeV).
- good spatial resolution, particularly for the gamma ray images as they are used to provide shape and density information [1]
- neutron detectors to be insensitive to both low energy scattered neutrons and gamma-ray background
- height of detector array to be greater than about 4300 mm
- for systems employing, say, 1000 individual detectors, the cost per detector channel should be low and preferably less than about US$200.
- good gain stability
- good high-count-rate performance with predictable deadtime
- reliability

A number of detection methods have been previously investigated for fast neutron radiography, including the use of scintillating screens with various readout schemes [3-6]. Unfortunately these detection methods do not meet all the requirements listed above, especially efficiency.

2. Fast Neutron Detector Array

High neutron detection efficiency is particularly important as the brightness of conveniently available neutron sources is low and scanning times are short (about 1-2 minutes per container). The most efficient fast neutron detectors are those based on proton recoil in plastic (or liquid) scintillators. Readout of the light from the plastic scintillators is performed using silicon photodiodes. Compared to photomultiplier tubes, silicon photodiodes are inexpensive, compact and rugged. In addition they only require low bias voltage (~50 volts) and they do not require gain stabilisation. The spectral response of silicon photodiodes is well matched to that of orange plastic scintillators that are available from a number of manufacturers.

Each plastic scintillator was 20×20×75 mm (Figure 1). The 75mm length of the scintillator was chosen to provide a good compromise between neutron attenuation and light collection.

The reflective coating of the scintillators was optimised to maximise light collection at the photodiode and to provide optical decoupling between neighbouring pixels. The conventional photodiodes we used are inexpensive but have no internal gain and produce a very small signal (a few thousand electrons) for fast neutrons. Signals from each detector channel are integrated using a custom-designed low-noise charge-sensitive preamplifier [7]. The millivolt signals from the preamplifiers are amplified and gaussian filtered to optimise the signal to noise ratio at about 10:1 to 20:1. Window discriminators on each channel select the unipolar signal pulses and reject noise from the preamplifier and from most of the radiation interactions directly in the silicon photodiodes. The discriminator upper and lower levels can be adjusted individually for each channel under computer control. There are no individual adjustments in the preamplifier/shaping amplifier channels.

Blocks of 16 neutron detectors are mounted onto a single circuit board and share common power supply and communication connections. The complete neutron detector array in the Brisbane scanner comprises 4 columns of 11 boards (Figure 2), for a total of 704 detector elements. Pulse height spectra from one block of 16 detectors irradiated with 14 MeV neutrons are shown in Figure 3. The neutron count rates per detector above the lower level discriminator with no intervening cargo are typically about 800 counts per second.

3. Gamma-Ray Detector Array

The gamma-ray detector array uses CsI(Tl) scintillator elements measuring 10x10x50 mm with the long axis aimed at the gamma source. The peak scintillation wavelength of CsI(Tl), around 550 nm, is well matched to the photodiode response. Reports in the literature on the optimisation of CsI(Tl) scintillator/ photodiode detector systems have shown that the coating of the scintillator in reflective layers gave optimum results [8,9].

Due to their smaller size, 32 gamma-ray detectors are mounted on each circuit board, which has the same footprint as a 16 channel neutron detector board. The gamma-ray detector array in the Brisbane scanner has a single column containing 11 boards, for a total of 352 detector elements. The detector electronics are similar to the neutron detector electronics except that smaller photodiodes are used and bipolar shaping is employed. The gamma-ray count rates per detector above the lower level discriminator with no intervening cargo are typically about 23,000 counts per second.

4. Detector Readout and Imaging

As the detector system comprises narrow, vertical columns of detectors, the cargo is moved through the fan-beams of radiation by a chain conveyor to build up a 2-dimensional image line by line. Control and readout of the neutron and gamma-ray boards is managed via a custom-designed, high-speed serial interface. Each of the boards in a column is daisy-chained together and connected to a PC. The temperature of the detector arrays is controlled at around

20^0C. The accumulated counts from each detector channel are read out each time the cargo on the chain conveyor has traversed 5 mm.The chain conveyor is typically operated at a speed of 1-2 m/min to achieve scanning times of approximately 1-2 minutes per ULD.

5. Summary

CSIRO has developed custom-designed neutron and gamma-ray detector systems, each comprising a large number of small detector elements. The size of the individual detector elements determines the final resolution of the scanned images. Both systems use scintillators to convert the incident radiation into a light pulse, which is then read-out using photodiodes and amplified and counted using custom-designed electronics. The detector system meet the requirements of high efficiency, good spatial resolution and low cost.

Acknowledgments

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Figure 1. Photograph of orange scintillators used in the neutron detector array in the CSIRO Air Cargo Scanner ar Brisbane Airport

Figure 2. Photograph of neutron detector boards being assembled for installation in the CSIRO Air Cargo Scanner ar Brisbane Airport

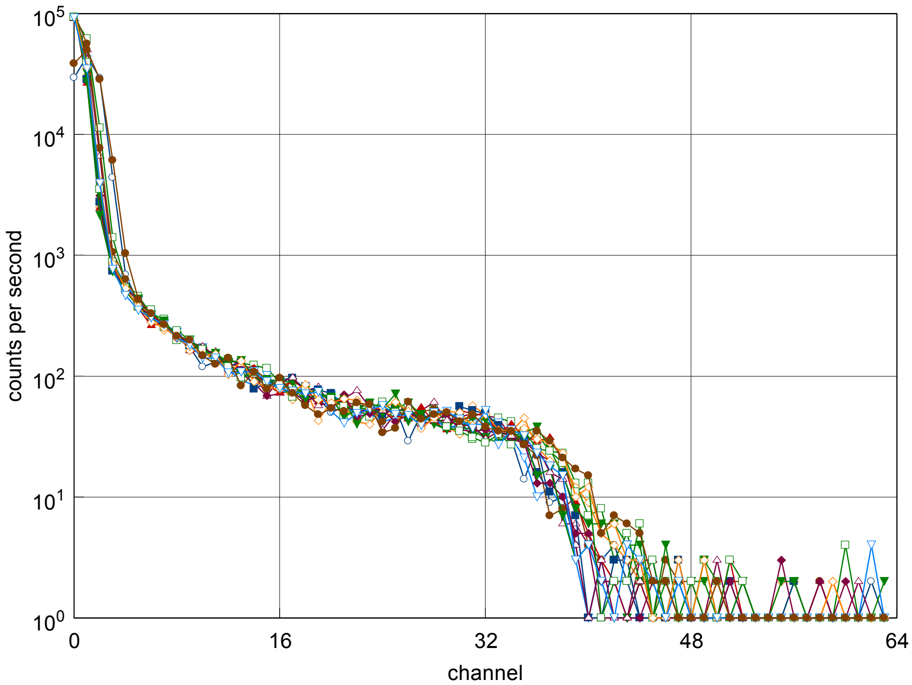

Figure 3. Pulse height spectra from all neutron detectors in one block of 16 detectors in the Brisbane scanner.